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Food Security and Employment under a Changing Climate in Mali: What Are the Options?

MALI

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Subject	**Food Security and Employment under a Changing Climate in Mali: What Are the Options?**
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List of abbreviations and acronyms

EKN	Embassy of the Kingdom of The Netherlands
GCM	Global Circulation Model
GDP	Gross Domestic Product
GE	Grain Equivalent (a measure for caloric nutrition)
Ha	Hectare
IFDC	International Fertilizer Development Center
IPPC	Intergovernmental Panel on Climate Change
Kha	1000 ha
Kton	1000 ton (1000000 kg)
MFA	Ministry of Foreign Affairs
Mha	million hectare
Mm	Millimetre
NCEA	Netherlands Commission for Environmental Assessment
NPK	Nutrients Nitrogen, Phosphate and Potassium (Kalium)
PSI	Planetary Security Initiative
SMEs	Small and Medium sized Enterprises
SWOT	Strengths Weaknesses Opportunities Threats
UTL	Unit of Tropical Livestock
WUE	Water Use Efficiency

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1. Introduction

The Netherlands Ministry of Foreign Affairs initiated in 2015 the first Planetary Security Initiative (PSI), followed by a second one in 2016. PSI now organizes a conference in December 12-13 of 2017 in The Hague, entitled "From Analysis to Action". On December 12, a workshop is programmed with the title "Mali's Fertile Grounds for Conflict: Climate Change and Resources Stress". Or, in short: the Mali workshop. More details on the discussion at the Mali workshop can be found on PSI's website.

On November 10, 2017, the Embassy of the Kingdom of The Netherlands in Mali, and the Directorate General for International Cooperation of the Ministry of Foreign Affairs, asked advice to the 'sustainability advice' facility of the Netherlands Commission for Environmental Assessment (NCEA). In particular to discuss sustainable development of Mali in light of climate change, insecurity and migration. Due to water scarcity, future climate change and future population size, it is assumed that food shortage and unemployment increasingly will become major factors driving Mali's development, and therefore its sustainability. It is assumed that improving food security and employment, with resource-efficient value chains, contributes to more social equality, less conflict over natural resources, and more security in general. More equality and security is assumed to enable more sustainable governance, with potential contributions to many sustainable development goals.

For this reason the following specific questions were asked to the NCEA:
- What is the status of food security in Mali?
- What is the potential of Mali to produce more food, including associated employment?
- How is this potential affected by climate change?
- What are preconditions for realizing this potential and creating employment?

Executive summary

What is the status of food security in Mali? In 2016, around 2.5 million people were considered food-insecure: almost 15% of the population.

What is the potential of Mali to produce more food? Mali has rather distinct agricultural production systems that collectively can ensure food self-sufficiency. A healthy but still moderate food supply for all in 2050 and 2100 would require food availability to increase about 3-fold and 6-fold respectively, compared to 2015. It is not impossible to achieve this in a sustainable manner by a combination of the following options:

- Rainfed agriculture can suffice to provide the population with a moderate diet up to 2100 (in particular maize, millet and sorghum). Water use efficiency can be dramatically increased through a comprehensive agronomic package of measures.
- Rice and irrigated cultivation can still be considerably enhanced, in particular by investing in water use efficiency and other improved practices. Irrigated rice remains a water-inefficient system, competing with more efficient agricultural water uses.
- The Inner Niger Delta in particular produces large amounts of irrigated rice, meat and fish. More large scale irrigation here may go at the expense of current water-based livelihoods, although some optimization is possible. A reliable estimate of the total potential of this area requires a more comprehensive assessment. Large-scale irrigated rice creates relatively less employment.
- Improving livestock cultivation is still possible, but highly depends on innovations in fodder supply. Fish production can increase by means of aquaculture.
- Cash crops and trade still have considerable growth potential, not so much for the already important cotton, but much more for exotic products; the potential could not be assessed in this study.

How is the potential affected by climate change? With current IPCC scenarios, the potential described above can still be realized, albeit at higher investment cost for additional adaptation measures. Sound knowledge and farm management and collective infrastructure management become more critical.

What are preconditions for realizing the potential and creating employment? Realizing the potential food production is the most realistic option to increase livelihoods and employment in Mali. Employment will be created in the primary production, but in particular along the value chain, such as in the input sector for service providers and agro-dealers and in food processing industries. Private and public actors together may give priority to value chains that give them most return-on-investment, as well as contribute most to sustainable development.

2. What is the status of food security in Mali?

Mali is a landlocked and geographically diverse country of 124 million hectares and a population of 18 million people, of which about 10% lives in the northern arid regions. It ranks among the poorest nations in the world, despite the overall drop in national poverty from 55.6% in 2001 to 43.6% in 2010, which however, rebounded to 45% in 2013. The economic growth rate has remained around 4.5% over the last decade and is projected to grow by around 5% over the period 2017-2019 (World Bank). The agricultural sector contributes about 40% to the GDP, employing about 70% of the population. In 2016, around 2.5 million people were considered food-insecure, with 315,000 experiencing severe food insecurity during the lean season. Around one in every three children under the age of 5 is affected by stunting caused by poor nutrition which affects physical and cognitive development. Food insecurity is related to environmental vagaries (S1) and the current status of food security remains poor and stressed (S2). Development of the agricultural sector is considered the only way out of poverty (World Bank, 2015).

3. What is the potential of Mali to produce more food?

Of the total land mass of 124 million ha, 41 million is considered agricultural land, of which about 35 million permanent pastures and a strongly varying annual acreages of 5-7 million arable land (Table A1, Figure A2a). While this variation is partly due to poor statistics, it is also climate related: farmers refrain from sowing when the onset of rainfall is too late, more so for maize than millet and sorghum. Cereal imports vary greatly as well, but not near compensating for the fluctuations in national production (Figure A2c). Yield, acreage and therefore production variability are related to environmental vagaries and detrimental for national food security (S1). The potential area suitable for arable cultivation is estimated at 12 million ha (e.g. FAO, 2003), which implies that the ability to bring land under cultivation limits production increase (World Bank, 2015). With irrigation infrastructure development in the 1980's and beyond, the total area equipped for large scale irrigation has increased to 380 kha in 2014 (Figure A3), but the total rice area reached 640 kha which includes upland rice and other smaller irrigated areas in inland valleys.

Mali has rather distinct agricultural production systems (Figure 1) that collectively can ensure food self-sufficiency. Specific emphasis should be placed on balanced development of different systems to meet the needs of different population groups. Employment generation, prevention of societal unrest, agricultural systems in harmony with ecosystem functioning and adaption to changing temperatures, along with the need for non-food services such as electricity generation, are some of the key development targets. This clearly asks for an integrated approach. Growing food demand due to rapid urbanization and a region with structural food deficit guarantee a solid uptake of increases in agricultural and livestock production (World Bank, 2015).

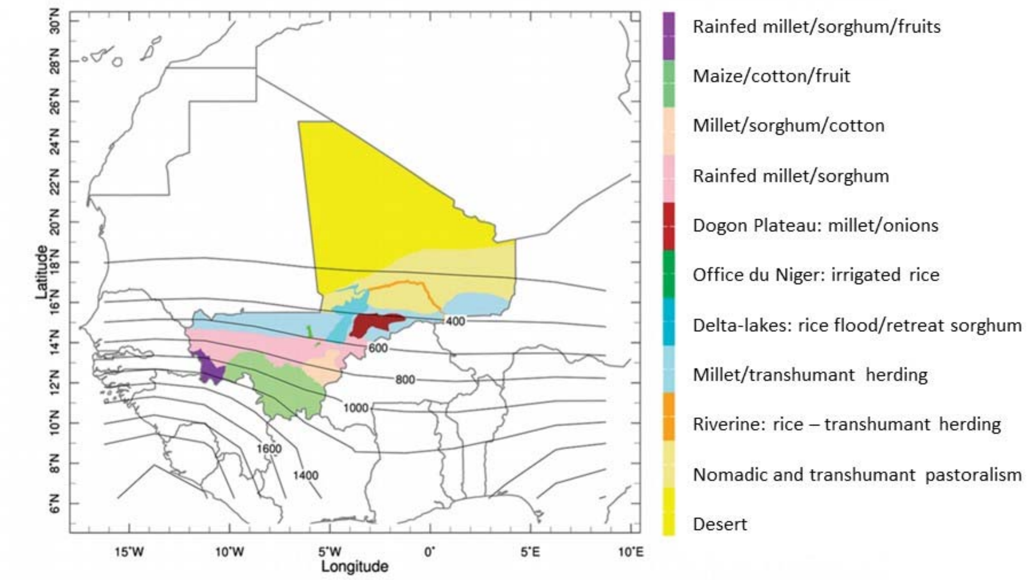

Figure 1: Livelihood zones as defined by the Famine Early Warning Systems Network in 2005, in color, overlaid by the 1979-2007 precipitation (mm y-1). From Giannini et al. (2017).

Cereal crops occupy 80% of the total arable land in Mali, the production of about 7 million tons (Table 1) implies a total production in Grain Equivalents (GE; WRR, 1995) of roughly 8.5 million tons. Meat and fish production of 3-400 kton (Figure A4a) approximates about 2-3 million GE. The total GE of about 11-12 over 18 million inhabitants suggest a consumption of about 1.7-1.8 kg GE p-1 d-1, which, on average, resembles a vegetarian diet with some meat consumption. A (healthier) diet of 2 kg GE for Mali raises food demand to 33Mton GE in 2050 for the projected 45 million inhabitants and to 68Mton GE for the 93 million inhabitants in 2100 according to the medium population growth scenario.

3.1 Rainfed agriculture

Most emphasis to increase food production is placed on the development of irrigated system along the floodplains of the river the Niger (S5), but the largest production gains can be achieved by closing the yield gap of maize, millet and sorghum. For these, rainfed yields of respectively 8, 5 and 5 t ha-1 can be obtained, up from the current 2.2, 1.0 and 1.0 t ha-1 (Figure A5a-e). This implies that, theoretically, crop production in Mali under rainfed cultivation can suffice to provide the population with a moderate diet even up to 2100 (Table 1).

Proper management of e.g. 500 mm rainfall in the season allows cereal yields up to 4-5 t ha-1, but the inherently low fertility of the soils heavily depresses yields. Fertilizer use in Mali in 2016 was 550 kt, equivalent to about 310 kton NPK nutrients, of which 80 kton for rice, 40kton for maize, 80kton for cotton and the remaining for sugarcane and other crops. Application rates per hectare reach 120, 60 and 110 kg ha-1 for rice, maize and cotton respectively, while sorghum and millet receive on average only 2 and 5 kg ha-1 (IFDC, 2017a). Application of 120 kg for rice can support yields up to 6-7 t ha-1 and 60 kg for maize can support about 3 t ha-1. Application rate for sorghum and millet may be complemented with an estimated 10 kg N ha-1 maximally from manure if available (Conijn et al., 2011), which can help to sustain one ton of yield. The use of fertilizer clearly demonstrates the large impact on yield, but lower current yields at given application rates suggest options for efficiency improvement. IFDC (2017) demonstrates for over 100 thousand farmers that use of appropriate fertilizers can significantly increase yields of rice, millet and sorghum with farm gross margins increasing respectively by US$578, 105 and $148 per hectare.

Table 1: Actual and potential production estimates (average 2010-2014 where applicable)

Crops	Actual area	Actual yield	Actual Production	Potential arable Area[2]	Potential/ Water-limited yield	Potential production
	kha	t ha^{-1}	kton	Mha	t ha^{-1}	Mton
Maize	690	2.3	1587	2 (1-10)	6-10	12-20
Sorghum	1260	0.9	1134	4 (2-10)	4-8	16-32
Millet	1760	0.9	1584	3 (2-10)	2-6	8-24
Rice	640	3.4	2176	2	8-11	16-22
Groundnut	350	1.3	455	1		
Total (2010-2014)	5000-7000		6900			
Cereal Potential				11000	5-10	55-110
Potential (all crops)				12000	5-10	60-120

[2] Total potential suitable arable land of 12Mha is arbitrarily distributed among maize, sorghum, millet and other at 2, 4, 3 and 1 Mha respectively, in addition to 2 Mha for rice (S4).

Proper harvesting of rainwater is essential to overcome periods of drought and prevent run-off. For example, through small infrastructure (like catchments and dams) and micro-catchment rainwater harvesting systems (like half-moon 'zai' techniques, contour ridges and stone lines). Such approaches were found to more than double yield and even allow double cropping in inland valleys in Southern Mali (Katic et al., 2014). These authors also report that use of groundwater, which is significantly present (S4), can allow double cropping and contribute greatly to improved farm income. The World Bank (2015) also argues that small-scale irrigation schemes are particularly attractive for poverty reduction as they benefit smallholders and have the highest rates of return on investment. (See S3) However, these water resources appear not to be economically exploitable for agricultural purposes (Passip, 2017). We recommend to reassess these options in view of synergies in production ecology.

High levels of ecological synergies can be attained through integrated management practices of fertilizer, water, plant protection, seeds and small mechanization. This may result in highest use efficiencies of inputs (Figure A6), and with that, lowest losses/emissions per unit product and higher economic returns. It may, for instance, take 5000 liters or more of water to produce 1 kg of grain at yield levels of 1 t ha-1, which can be reduced to only 2000 and even down to 1000 liters at yields exceeding 5 t ha-1. Moreover, integrated management can improve soil organic matter during the first 2-3 decades sequestering 200-1000 kg carbon per hectare per year to level off in 4-5 decades to zero. Hengsdijk and Keulen (2002) demonstrate agronomic management packages to increase yield and reduce production variability of millet. A comprehensive agronomic approach would help realize food security and water utilization through resilient production systems, as laid out in the plans of the Netherland Embassy in Mali (EKN_Mali, 2014).

3.2 Rice and irrigated cultivation

About half of the total rice area is under rainfed cultivation in inland valleys in southern Mali, with local varieties Gambiaka and some Nerica lines. Rainfed yields are low, primarily due to poor water control, weed infestation and low fertilizer use. Irrigated cultivation is presumed to escape the vagaries of rainfall and massive investments by the Malian Government (and its development partners) from the 1980's onwards in irrigation infrastructure in the Niger delta made it possible to quadruple rice production. The potential for irrigated cultivation is estimated at 2.2 million hectares, with approximately 456 kha in 2016 (Passip, 2017; Figure A3; though presented numbers seem not entirely consistent – see S3), part of which is cultivation.

Water use efficiency (WUE) of rice cultivation in the (outer perimeters of the) inner Niger delta can be improved through maintenance and investments in current irrigation and drainage systems. Expansion of irrigation in the outer delta could be achieved through savings from improved water use efficiency, rather than extraction of additional water. Moreover, improved agronomic practices – i.e. balanced crop nutrition, fertilizer deep placement, more productive varieties, weed management and the like – can easily increase productivity by 25% or more. More practically considered, an additional 100 kha could be brought under irrigation in the outer delta producing (S3). Improvements of water catchment structures can improve flood irrigation, which provides considerable scope for expansion of vegetable production in the dry season.

3.3 The Niger delta

The wetlands of the Inner Niger Delta of an area as large as Belgium, covers 1.6% of Mali, provides pasture for one third of the cattle and delivers 8% of the GDP (Wetlands International, 2017). Dry periods followed by flooding during rainy seasons are a main source for biodiversity, fisheries, fuelwood and fiber, wet soils for crops and pastures on receding water from flooded parts during dry seasons. Wetlands International (2017) estimates that these agro-ecological production systems of the delta can provide livelihood for up to 2 million people. Unintended implications of dam construction and water diversions to irrigated (rice) cultivation have reduced variation in water flow and heavily affected the livelihoods of fishermen, nomads and agriculturalists who depend on the flood plains (S5). An integral approach, including water infrastructures of dams and canals that can maintain seasonal floods and droughts cycles, could partially re-install the co-existence between fishers, farmers and herders. Systems include rainfed crops on the upper parts, dry-season crop adjacent to the flood line, flood-recession cultivation on the parts that seasonally inundate and rice on flooded parts. The pasture during the dry season and the tall grass Bourgou that grows on flooded parts are essential for nomadic cattle raising. Irrigated rice is grown on the flat "outer" perimeters of the Niger.

3.4 Livestock and Fish

Meat production from indigenous livestock, primarily cattle, sheep and goats, has grown from 150 kton in 1990 to over 300 kton in 2014 (Figure A4a). The increase is entirely due to the increased number of livestock slaughter as the carcass weight has not changed at about 130 kg for cattle and ten times less for goats and sheep. The current stocking rate of about 13 million livestock units, that provide additional services than meat alone, already exceeds

the maximum carrying capacity of the grasslands (S6). Improving livestock cultivation implies increasing grassland productivity or integrating nomadic systems with feedlots, which inherits a great potential to enhance overall productivity (yet, see S7). The feedlots could be located close to urban centers where demand for animal products is highest. This requires agricultural intensification to improve the quality of crop residues and pastures (like cotton cake and potentially through leguminous forage crops). Without innovations in livestock production systems, nomads, in search for grazing grounds, will increasingly move southwards, which may partially be halted only by the Tsetse fly.
FAO presents "standardized data" only for freshwater fish harvest which reveals a capricious pattern with stark declines in the 1980's and 1990's to recover after 2000 to levels of the 1970's (Figure A4a). Passip (2017) suggests total production from lakes and rivers to reach 180 kton, which is about twice the amount reported by FAO. Aquaculture appears to be modest at only 2.4 kton in 2015, but with an ambitious plan for increase to 37 kton by 2020 (Passip, 2017), with an estimated potential production of 200 kton of fish per year by the Ministry of Agriculture (PDA, 2013; S4). Implications of production increase should be thoroughly understood in view of scarce water resources.

3.5 Cash crops and trade

Mali is hardly integrated in world trade and national agricultural value chains are also poorly developed (S8). Cotton is the only significant exported commodity (Table A2), grown by commercially oriented smallholder farmers in southern Mali. The commodity faces some significant challenges such as sub-optimal integration in the world market, state controlled systems, and few options to add value such as through fair trade in addition to production of seed, case and lint. Whereas cotton is perceived as a bastion of poverty reduction, the region has a surprisingly high rate of malnutrition (S9).

Next largest export commodities include cashew, sesame (though not reflected in the FAO data of 2013), and mangoes. Informal sectors include commodities of indigenous tree species like shea nut and butter and markets such as Soumbala (popular widely used local food seasoning derived from the néré tree) and baobab products with considerable potential. But also, could nomadic beef, goat or sheep meat be turned into a lucrative "exotic" markets? Most products are however exported unprocessed with little added value. Rice is considered a cash crop that serves the guaranteed local market. Most important imported commodities are food crops, including wheat, rice, potato and sorghum.

Interestingly, the Netherlands is exporting several products to Mali and Western African countries that could be locally produced, like onion, potatoes and dairy products. The Netherlands could support with knowhow to stimulate local production, as for instance plead for by the Netherlands ambassador in Ghana and being implemented by Friesland-Campina in Nigeria and Heineken in Nigeria and Ivory Coast (S10). Mali has identified mango, papaya, potato, shallot / onion, banana, cashew and sesame to have comparative advantage and market opportunities (S4).

4. How is the potential affected by climate change?

Much of the population is dependent on local agriculture and therefore directly affected by climate variability. Poverty limits options for adaptation which may exacerbate food insecurity, such as during the intensive periods of drought during the 1970's and 1980's. Rainfall has however, recovered over the past decades to normalcy. Seasonal rainfall is predicted by Global Circulation Models (GCMs) not to change due to climate change for Mali (IPCC, 2014). Maximum and minimum temperature are predicted to increase by 2.9 ℃ and 3.3 ℃ (S11). Mitigating measures to prevent loss of yield potential include proper soil fertility and organic matter management, temperature adapted varieties, integrated water management, and the like, which resemble similar interventions to raise overall productivity and increase systems resilience.

Nomadic livestock systems might be more resilient to higher temperatures than arable cultivation if wetlands are maintained (Pedersen and Benjaminsen, 2008; Mertz et al., 2011). IPCC (2014) also calls for improving resilience to climate change through protection and enhancement of natural ecosystems that provide a buffer against climate extremes. Advanced water management practices that warrant a "living" Niger basin where flood pulses are maintained to sustain the multiple services for fishermen, farmers and herders, could mitigate some of the most pressing problems arising from large scale dams and irrigation systems.

5. Preconditions for realizing the potential and creating employment - An inclusive agricultural development strategy

Mali ranks low on the economic complexity index. This reflects an economy mostly based on basic products and suggests that opportunities for future diversification are primarily in agro-processing. The World Bank (2015) prominently states that the scope for economic transformation is limited until 2030 with opportunities for poverty reduction to be found in the rural sector. A successful poverty reduction strategy will thus need to start by raising the incomes of those engaged in the primary sector and by putting in place the foundations for economic transformation. In crafting a comprehensive development strategy, it is worth noting that the African continent, including Mali, is not handicapped by the head start of developed nations and can leapfrog development. ICT and mobile services can help to optimize input use and services (S13). Solar panels may prevent use of firewood that degrades the already fragile environment and reduce health hazards from smoke (S14). Moreover, advanced technologies, such as in breeding and innovative fertilizers, can boost productivity and efficiency (S15). Then, modelling approaches can help to systematically identify agricultural development opportunities in spatial and temporal aspect. An example is the "Geopolitical Lens to Climate Smart Food Security Interventions" (NCEA, 2016), that aims to identify areas with high potential for effective climate smart aid and trade interventions (S16).

There is abundant evidence that agronomic potential will be attained, if backed with robust economic policie is and enabling initiatives that build the micro-economic foundations for transformation. This can lead to global and domestic agro-food chains that structurally contribute to inclusive economic growth (Maatman et al., 2011). Falconnier (2016) indeed found that neither individual policy interventions nor agricultural strategies alone could raise the farm population above the poverty line and improve food security for several farm types in southern Mali. Rather a comprehensive set of interventions had to be simultaneously implemented, which in their analysis included input/output subsidy for cotton and milk production + family planning + job creation outside agriculture + integrated pest and weed management with small mechanization and extended subsidies on fertilizers for sorghum and millet. Therefore, policies and interventions should advance from singular foci of agricultural intensification to multi-sectoral approaches. These comprehensive approaches are in line with insights about development of value chains that require new forms of production, technologies, logistics, labor processes, organizational relations and networks (Trienekens, 2011).

Creation of employment, in particular for youngsters and females in agri-business is essential to advancing the rural economy. Yet, labor data by most institutions are presented as aggregate amounts in the agricultural sector. Data about labor requirements per activity in agricultural production systems is barely available (S12 for some data). Initial evidence from ongoing programs suggest however, significant potential for employment creation through multi-sectoral value chain development.
2SCALE (2SCALE, 2017) is a Netherlands supported development initiative that works with inclusive business champions – of African or foreign origins – and other relevant private and public partners. The initiative aims to develop partnership and business models that promote inclusiveness, develop (new) competitive edge, and have potential for scaling. Activities of 2SCALE include:

- identification of market opportunities;
- support to technology and organizational innovations in farming, post-harvest handling and processing;
- capacity strengthening of farmer groups and small enterprises;
- brokering, trust and relationship building within agribusiness clusters and value chains;
- financial intermediation;
- targeted interventions for base-of-the-pyramid consumers.

Several successful 'inclusive business models' have been developed that are ready for scaling and replication. In Mali, the 2SCALE portfolio consists of:

- sesame, with PROSEMA as the business champion;
- maize/ SONAF; cassava (*attiéke*)/ women processors;
- parboiled-rice/ women processors;
- vegetables/ East West Seed International and producer groups;
- potatoes/ producer groups.

Results to date include almost 100,000 smallholder farmers reached. These farmers are benefitting from target value chains, and have strengthened their capacity to produce and negotiate profitable conditions. Onion productivity for instance has increased by over 300% to 30 tons/ha; over 150 SMEs have been strengthened (25% of them women-led) and effectively participate in commercially viable value chains; 0.5 million Euros in loans/ credit mobilized in 2016 alone. Total investment in the six partnerships equals about 5 million Euro, from June

2012 – 2016, of which 2.5 million Euros private sector co-investment. This investment of about 50$US per farmer comes with additional non-tangible benefits. These include inclusiveness, connectedness, trust, willingness to co-invest and benefits that last beyond the program duration. This is social capital that is one of the essential assets in livelihood strategies of farm households (Amartya Sen) and cement for societal development.

6. Synthesis

The above information about the actual and potential characteristics of the various production systems could be condensed in a spider diagram (Figure 2). It represents a modified SWOT analysis based on presented information and expert assessment. The diagram projects the current (left) and potential (right) characteristics of seven agricultural production systems (sorghum and millet taken together). Rice cultivation has been separated in large-scale irrigation and inland valleys systems, because of their very distinct nature. The web is currently small, and grows, revealing that much of the potential is yet to be unlocked. Current lack of control over production factors results in low yields and poor stability due to high climate sensitivity. This results in low resource use efficiencies and labor productivity. Yet, integrated management approached can substantially improve most of these factors.

The contribution to food security can be highest for maize, millet and sorghum. Investment in rainfed production is assumed to generate more labor than larger scale irrigated rice. With that this also inherits more opportunities for inclusiveness of youth and women, certainly so through the development of value chains. The trade value of cash crops could be further improved. Not so much for cotton, but more so for exotic niche products. However, the absolute contribution to food security may likely remain low. Water use efficiency can be dramatically increased through a comprehensive agronomic package – also and particularly for rainfed systems – while irrigated rice remains a water-inefficient system.

The development of rainfed agriculture calls for comprehensive and persistent long-term interventions with gradual improvements of productivity over time. This will generate considerable job opportunities in agriculture, foremost in the food value chain. Moreover, development of rainfed systems will be climate smart because of the need to increase soil organic matter, which implies the sequestration of carbon. Yet, this avenue is less prestigious, and with less obvious quick gains, than large-scale infrastructural interventions such as dams and irrigation schemes, despite the latter having a higher cost-benefit ratio and generating of less employment.

In the case of Mali, the geographical spread of the various production systems warrants more emphasis on the development of rainfed systems in the southern, most densely part of Mali. Animal production will face severe limitations when not integrated with cropping systems. Increasing the carrying capacity of the Inner Niger Delta will remain limited and calls for balanced strategies.

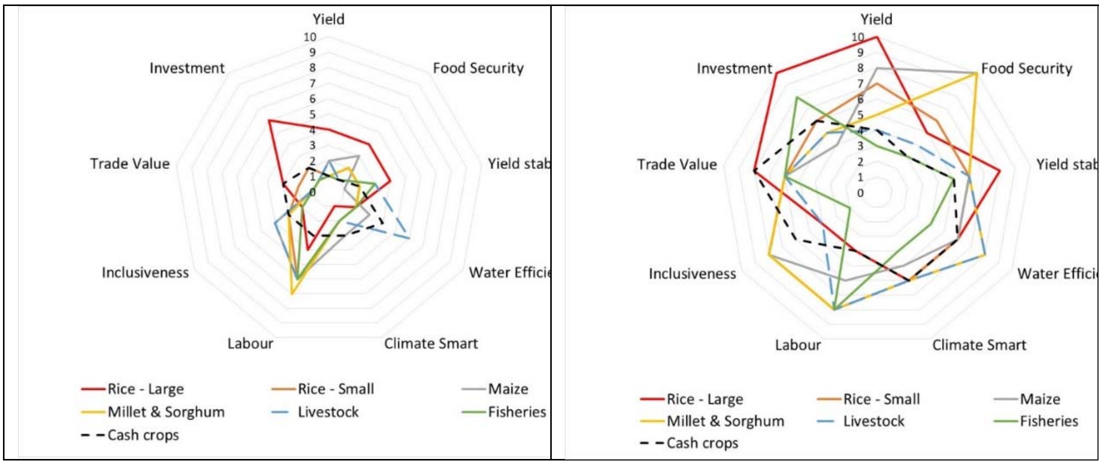

Figure 2: A spider diagram presenting the SWOT of seven production systems for a set of characteristics relevant for this study.

7. Supplemental reading

S1. Johnson and Brown (2014) found variation in NDVI (i.e. crop/land greenness index observed through satellites) in four West African countries to relate to child stunting (i.e. reduced height-for-age which reflects the poor long-term nutritional status of a child) and for Mali even to child wasting (i.e. reduced weight-for-age which reflects an acute, poor short-term nutritional status of a child). This provides evidence of long- and even short-term implications of drought and climate variability on health and nutrition outcomes, pressing to urgently find mitigation measures to environmental vagaries.

S2. FAO-GIEWS (2017) and FEWSnet (2017) forecasted total cereal production in 2016 to be up due to favorable weather conditions during the cropping season to reach 9.0 million tons, up from the 8.1 in 2015 and around 6-7 in the 5 previous years. A “minimal food insecurity” continues throughout most of the country, but according to these references, poor households from previously flooded areas, and those in the western Sahel that experienced an early lean season and have resorted to borrowing and to reduction of non-food purchases, are “stressed” from May until September 2017.

S3. Water management is essential for food security and a national irrigation plan is currently under development. A clear distinction should be made between “total water control” such as in the Office du Niger for rice cultivation, and “partial water control” in small scale systems, such as through small reservoir or flood irrigation in inland valleys. Current plans for large scale expansion at 10 kha y^{-1} in the Office seem unrealistic as expansion rates so far have not exceeded 5 kha (Pers. Comm., R.Groot IFDC), with development costs of 8,000-27,000 \$US ha^{-1} for irrigation schemes (Becker and Johnson, 2001). The current irrigated area of 120 kha can be expanded to 200-250 kha without extraction of additional water which reveals the low use efficiency of water. Exceeding an irrigation acreage of 400 kha would incur significant unintended consequences. Growing a second non-rice crop like vegetables in the dry season on residual moisture of irrigated systems could significantly improve the utilization of the land and water resources, and may be essential to ensure the livelihood of famers with limited land (e.g. Connor et al., 2008). Water use efficiency in small scale operations generally exceeds those of large scale infrastructures, and may contribute to higher production volumes and higher economic returns (also on investment) with the participation of larger number of small farmers and employment. The latter may allow a wider diversity of cropping systems ranging from maize, and even sorghum and millet, to higher value vegetable and fruits. Integrated practices result in climate smart practices as the increased biomass from fertilization can be incorporated into the soil where rates of 1 to 6 tons per hectare can improve soil organic matter during the first 2-3 decades sequestering 200-1000 kg carbon per hectare to level off in 4-5 decades to zero. Becker and Johnson (2001) showed that intensification of rice in inland valley swamps can produce up to 6 t ha^{-1} (also Fu et al., 2009).

S4. The Ministry of Agriculture (PDA, 2013) in its strategic plan aims to make Mali an emerging country where the agricultural sector is an engine of the national economy and food sovereignty guarantor. Priority is given to development of irrigated systems, and strategies are presented for livestock improvement and fisheries. Virtually no mention is made of maize, millet and sorghum, apart from "a seed sector based on strong involvement of the socio-professional organizations and private economic operators will be strengthened". The plan does mention small scale irrigation schemes for poverty reduction at the local level, but not in the context of cropping systems. In addition to surface water, groundwater resources are estimated at 2,720 billion m^3 with a recovery rate of 66 billion m^3 y^{-1}. Interestingly they estimate a considerable convertible aquaculture potential with 5,500 sites covering 895,000 hectares of lowlands, ponds and plains, which are hardly developed, but could potentially produce 200 kton of fish per year. Mali is considered to have a comparative advantage and market opportunities in mango, papaya, potato, shallot / onion, banana, the cashew, sesame. Noteworthy is mentioning of Jatropha in their energy policy, but no mention of solar technology (though that might have been considered outside the scope of agriculture).

S5. In the aftermath of the great drought of the 1970's, the government and aid agencies invested in dam construction for hydropower and to manage flood pulses for controlled crop production. The number of fish species are, however, reported to reduce and migrating birds from Europe are in decline (Zwart et al., 2009); deforestation and farming of fragile soils cause sedimentation of river channels; and reduced water availability have forced rural communities to migrate further south to more humid conditions (Tayaa, 2005). A downward spiral of ecosystem degradation affected the balanced utilization of the agro-ecosystems of the delta and jeopardized the livelihood of many, because of lower fish, rice and livestock production (Zwart et al., 2009; Brouwer et al., 2014). Moreover, intense drought, partly due to the described unintended implication of the large-scale water management practices, leads to regional conflicts (e.g. Benjaminsen, 2008 for Mali, but also Tayaa, 2005). Human migration from the region – one of the coping strategies to impoverishment – has been blamed to desertification after the droughts of the 1970'a and 1980's, but rains have since recovered while wetlands remained diminishing. Migrants do not only remain in the region but leave for Europe, estimated at about 300.000 people leaving from the Sahelian region from January to November 2016, almost all male (IOM, 2016). More than half of these are from the wetland areas with close to ten thousand from Mali during that period (Wetlands International 2017).

S6. Breman in 1975 estimated the maximum stocking rate of livestock for Mali at 12 million UTL[1] with a rate before the drought of the early 1970's at about 6 million. The total number

[1] Unit of Tropical Livestock = hypothetical animal weighing 250 kg

of head of about 15-17 million in the late 1960's indeed approximates 6 million UTL[2], and the number of head in 2012-2014 of 40-45 million (Figure A4b) relates to about 13 million UTL, which already exceed the maximum carrying capacity of the grasslands.

S7. The integration of crop and livestock systems constitutes a great potential to enhance overall productivity. However, the nomadic and sedentary systems face major constrains. The encroachment of sedentary arable farming systems on 'traditional' dry-season pastures in the savanna regions prevents the optimal use of high-quality wet season pastures in the northern Sahel. By integrating animal husbandry with arable farming, the traditional semi-nomadic systems could serve as 'delivery room', providing young animals that could be fattened in the savanna (Figure 3). Yet, pastoral specialization and mobility appears the most effective survival strategy for livestock keepers in the West African Sahel (Pedersen and Benjaminsen, 2008). They found children of pastoralists to be better nourished than children of sedentary farmers and that the children of the sedentarized nomads seem to be the worst off. They argue that diversification is flawed for mobile pastoralists in the northern Mali because the logistical and organizational costs of combining different modes of livelihood are large and insurmountable for a single household. This suggests that value chains that link livestock keepers to agriculturalist might be most effective, but which will require dramatic system changes in production-ecology and human behavior, foremost trust for mutual interdependence.

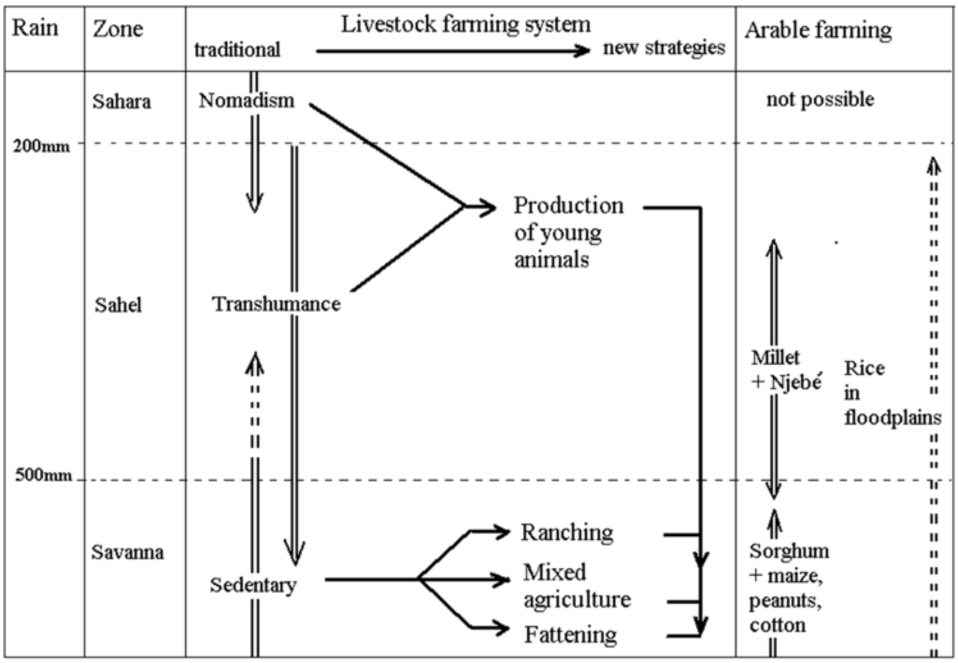

Figure 3: Integration of nomadic, semi-nomadic (transhumance) and sedentary systems to enhance productivity. Source: Van Keulen and Schiere, 2004.

[2] 1 cattle= 1 UTL for 60 percent of livestock and 1/2 UTL for the remaining 40 percent; 1 sheep = 1 goat = 1/10 UTL. 1 horse = 1 cameline = 1 UTL

S8. Mali is hardly integrated in world trade and national agricultural value chains are also poorly developed. Cotton, by far the largest trade commodity of Mali is for instance poorly integration into the world market is low due to Mali's landlocked geography, poor road system, and state control over the cotton industry (Baquedano et al., 2011). Small and medium sized enterprises are scarce as it is hard to compete against several layers of informal traders who may not pay tax, lack of standards for quality grades, not even weights, and small quantities of products per farm, which hampers development of storage facilities (World Bank, 2015). Therefore, strong farmer cooperatives could aggregate their scale to better access markets and obtain better terms of trade for inputs and outputs and other services like access to finance and training.

S9. The Compagnie Malienne pour le Développement des Textiles (CMDT), managed the vertical integration of the value chain and channeled resources into schools, adult-literacy, extension services, clinics, and road maintenance. Whereas cotton is perceived as a bastion of poverty reduction, there is a surprisingly high rate of malnutrition in the region of Sikasso, though Cooper and West (2017) could not attribute this directly to cotton cultivation. Cotton production reached about half million tons in 2014/15. Basset (2010) found that certified fairtrade cotton programs in Mali could not improve farm income, because this market does not eliminate the fundamental inequalities of international trade and power relations, though stimulates women's participation in cash crop cultivation and improves cotton quality.

S10. The Netherlands exports large amounts of onion to Western African countries, including Senegal (168,810 ton), Ivory Coast (73,089 ton), Guinee (39.776 ton), Mauritania (35.540 ton), and smaller amounts to Mali, that could also be produced locally. Notably, the Netherlands ambassador called for instance finds import of onion from the Netherlands into Ghana unacceptable as it can be produced locally. The Netherlands could support with knowhow to stimulate local production, e.g. by exporting high quality seeds and agronomic recommendations.

S11. Increasing temperature can dramatically reduce yield (e.g. Sultan et al., 2013). Traore et al. (2017) modelled maize grain yields decrease of over about 50% under current farm practices for the Sudano-Sahelian zone of Mali, which could be partly mitigated by recommended fertilizer use. Millet yield losses were only 7% to 12% that could be totally mitigated or even increased by use of mineral fertilizers. The analysis further showed that food availability is expected to reduce for all farm types, but large and medium-sized farms can still achieve food self-sufficiency if early planting and recommended rates of fertilizer are applied. Overall, measures to cope with the naturally occurring rainfall variability and to mitigate temperature impact on Malian agriculture include appropriate varieties (e.g. Sultan et al., 2013), micronutrient containing fertilizers (Dimkpa et al., 2017), integrated water management, and the like, which resemble similar interventions to raise overall productivity and resilience.

S12. Labor requirement in agricultural production systems for the specific case of Mali are difficult to trace but some indicative numbers can be derived from literature. Cultivation of millet require between 50 and 100 man days per hectare (Hengsdijk and van Keulen, 2002). Maize cultivation may need up to 50-60 labor days per hectare, while vegetables and fruits such as watermelon can exceed 160 days (in China though; Huang et al., 2015). More integrated systems like intercropping generally increase labor requirement. Clearly labor should be remunerative which should be ensured by increasing economic productivity, generally with yield increase as a driver. Moreover, labor intensity decreases over time as mechanization is introduced for intensification (e.g. Rodenburg et al., 2015).

S13. The use of advanced ICT, including close and remote sensing and mobile phones, inherits great potential to help target interventions in the highly diverse abiotic production environment of poor soils and erratic rainfall. The effectiveness of agronomic interventions will dramatically increase when expected rainfall and approaching biotic stresses can be anticipated, such as through satellite-based short-term weather forecasts and dispersion of diseases. These technologies could for instance dramatically reduce the costs of on-the-ground weather programs that had appeared to be expensive in the past (Passip, 2017). A good example is given by Ignitia (http://www.ignitia.se), a commercial company that provides accurate rainfall predictions made available by mobile phone, which is purchased by farmers to anticipate activities like timely land preparation and sowing to rainfall events. Satellite images allow even monitoring of child malnutrition as related to environmental stresses which allows timely interventions to prevent human suffering and to develop an adaptive response to climatic variability. ICT facilitates development of advanced administrative systems such as of vouchers for subsidies.

S14. The abundance of solar radiation inherits an interesting investment option for Mali in solar energy. The production of small amounts of biofuels for local use, e.g. through Jatropha grown as hedgerows, can help to kickstart rural development such as to run irrigation pumps or light vehicles for transport (Favretto et al., 2013). Decentralized energy systems of solar panels and small community-based bioreactors can provide energy in remote areas, freeing up labor currently required for collecting of scarce firewood, improving cooking and reducing the need for fossil fuels, while preventing further degradation of the landscape. Improved cooking conditions can dramatically reduce health hazards from smoke.

S15. Key agro-technical investments to boost productivity and generate employment along the value chain include innovative fertilizers and fertilization technologies (Bindraban et al., 2015), small scale water basins, improvement of the harvest index of millet and sorghum (ICRISAT, 2017), introduction of small machines for effective management of soil, weeds and diseases.

S16. The Dutch Sustainability Unit of the Netherlands Commission for Environmental Assessment (MER, 2016) developed a “Geopolitical Lens to Climate Smart Food Security Interventions” to identify areas with high potential for effective climate smart aid and trade interventions. The insights should support development of strategic donor plans, food security investment plans, and serve as input to the appraisal of potential geopolitical externalities of climate resilience, like migration effects. The methodology overlays 1) regions with dynamic food systems, i.e. low/high demand due to nearby cities or harbors, poor/strongly developed market infrastructures and little/large presence of private investors, with 2) regions with high/low vulnerable production system to the expected climate change, and with 3) areas that are at risk for conflict. The vulnerability of production systems relates to overlays of rainfall and its variability, the proximity to lakes and rivers for irrigation, the share of cropland within a grid cell etc. (Ruben et al., 2016). The methodology suggests most dynamic food systems with low climate dynamics to occur near Bamako, Sikasso and Ségou (Figure A7) while the remainder of Mali could be classified as less effective regions for aid and trade interventions that can be considered to be climate smart. Infrastructure is known to have an overriding impact on market development, but for the case of Mali, factors causing migration or lack of agricultural intensification have not been captured through this method. The potential for agricultural intensification, the un-intended consequences of large scale irrigation interventions that has triggered migration, and narratives about niche markets for rural and value chain development, along with the notion that rural development is prime pathway to set the foundations for economic growth and poverty reduction, present a more divers and promising picture for realizing food and nutrition security for the Malian population under changing climate, including trade opportunities, than suggested by the climate lens. A scenario of increased population by 2030 expands the favorable investment areas near the cities, but changes in infrastructure, technology and politics may rapidly alter the outcome of the methodology.

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Annex 2: Data of food and agricultural variable for Mali

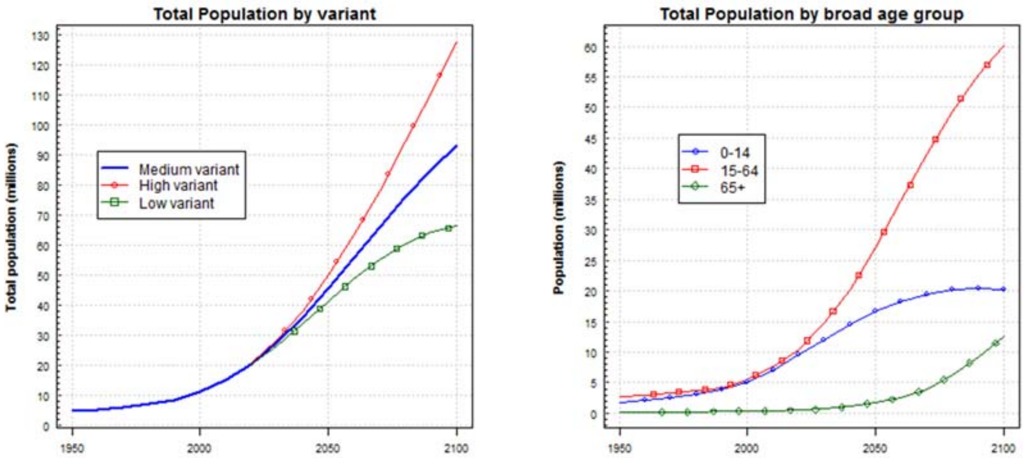


Figure A1 : Population projections Mali. Source https://esa.un.org/unpd/wpp/Graphs/DemographicProfiles/

Table A1: Highly varying cropping acreage (*1000 ha) of largest crops in Mali

	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Millet	1463	2284	1874	1437	1743	100	156	128	98	119
Sorghum	1220	1685	1246	938	1205	100	138	102	77	99
Maize	504	925	579	641	803	100	183	115	127	159
Rice, paddy	472	830	617	605	684	100	176	131	128	145
Groundnuts	337	340	344	373	352	100	101	102	111	104
Seed cotton	250	478	521	481	540	100	191	208	192	216
Cowpeas, dry	239	262	265	254	353	100	110	111	106	148
Sheanuts	67	80	82	78	19	100	119	122	116	29
Fonio	67	65	44	35	56	100	98	66	52	83
Vegetables	50	50	52	54	61	100	101	105	108	122
Cashewapple	46	42	38	29	36	100	91	83	63	79
Bambara beans	37	35	35	37	38	100	94	94	100	102
Sesame seed	32	39	58	37	54	100	119	179	114	167
Watermelons	24	20	22	25	27	100	84	91	103	115
Sweet potatoes	11	15	17	19	24	100	134	153	172	217
Total (Mha)	4.8	7.2	5.8	5.1	6.1	100	148	120	105	125

Source: FAOstat, June 2017

Table A2: Export and import of most important crops and livestock commodities in Mali, 2013

Commodity	Export Quantity	Export Value	Commodity	Import Quantity	Import Value
	tonnes	1000 US$		tonnes	1000 US$
Cotton lint	162739	296265	Wheat	227447	76627
Cotton, carded, combed	143935	373821	Rice total (milled eq.)	108558	50706
Cashew nuts, with shell	5983	3315	Oil, palm	31502	38801
Mangoes	5301	8188	Flour, wheat	30308	18458
Beverages, non-alcoholic	4234	1183	Food prep nes	24447	89246
Fruit, prepared nes	2189	1872	Cake, cottonseed	11601	3457
Cake, rapeseed	1949	317	Potatoes	10689	6204
Beans, green	1780	525	Sorghum	9167	3219
Cake, cottonseed	1629	255	Pastry	5435	6508
Maize	1447	23	Beverages, non-alcoholic	5182	4810
Groundnuts, shelled	1436	211	Maize	2061	522
Flour, wheat	1350	432	Hides, nes	363	87
Pastry	798	270	Cashew nuts, with shell	357	46
Almonds shelled	575	913	Soybeans	243	11
Food prep nes	514	306	Fruit, prepared nes	106	161
Potatoes	416	28	Chillies & peppers, green	83	15
Cotton waste	385	436	Tobacco, unmanufactured	59	4
Millet	322	87	Groundnuts, shelled	28	2
Tobacco, unmanufactured	278	13	Cotton, carded, combed	12	12
Hides, nes	261	405	Beeswax	11	24
Oil, palm	183	176	Almonds shelled	5	9
Flour, mixed grain	178	109	Cake, rapeseed	1	0
Vegetables, dehydrated	145	51	Vegetables, dehydrated	1	1
Beeswax	116	813	Cotton lint	0	1
Rice total (milled eq.)	86	196	Mangoes	0	0
Wheat	81	13	Beans, green	0	0
Chillies and peppers, green	9	461	Cotton waste	0	0
Soybeans	7	2	Millet	0	0
Sorghum	0	0	Flour, mixed grain	0	0

Source: FAOstat, June 2017

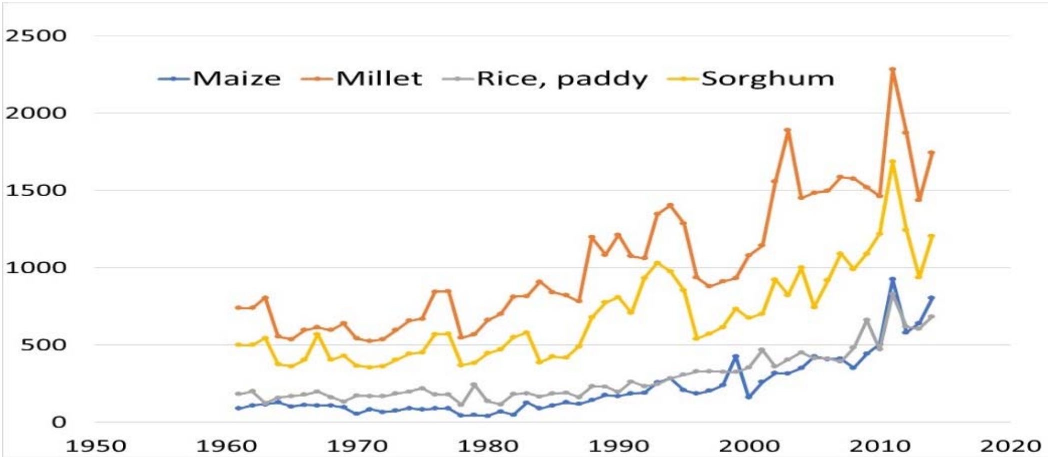


Figure A2a: Acreage of largest crops in Mali (*1000 ha) (FAOstat, June 2017)

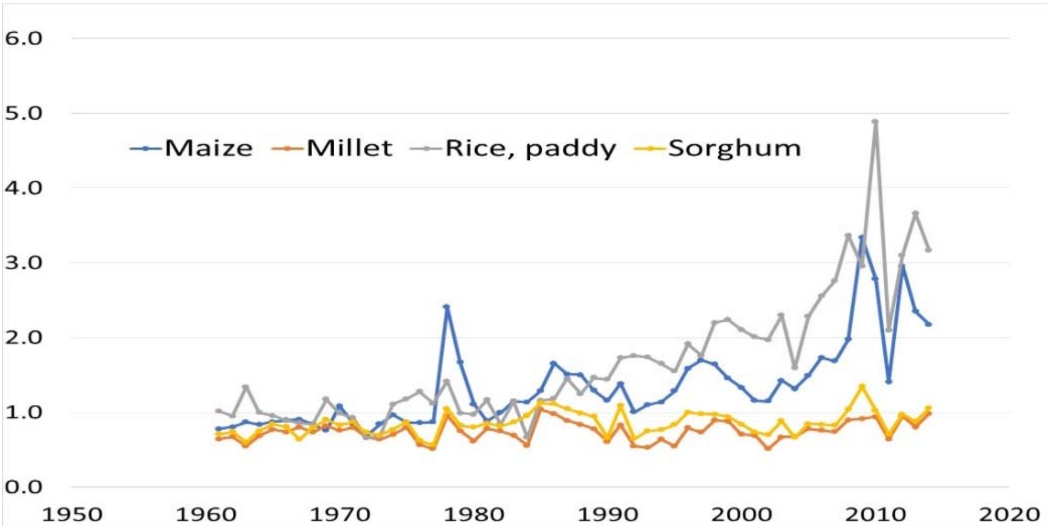


Figure A2b: Yield of largest crops in Mali (t ha^{-1}) (FAOstat, June 2017)

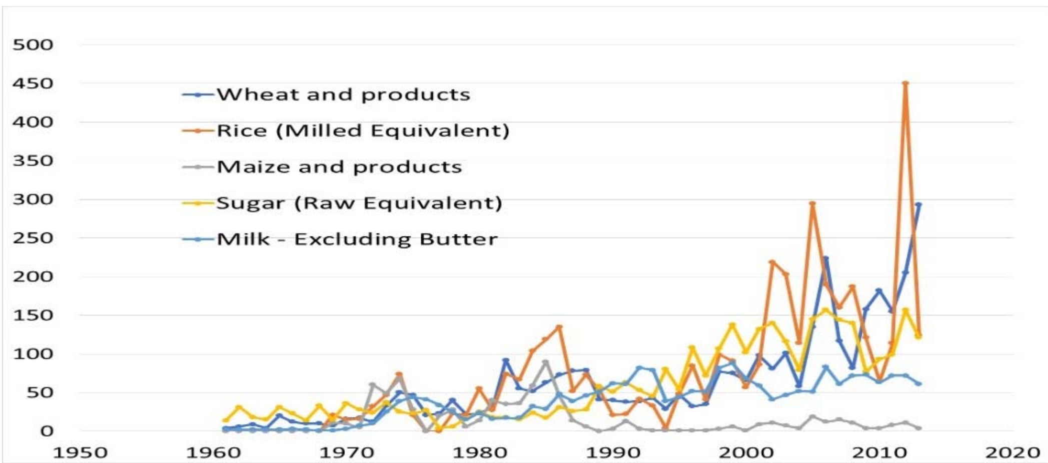


Figure A2c: Import of largest commodities in Mali (*1000 t) (FAOstat, June 2017)

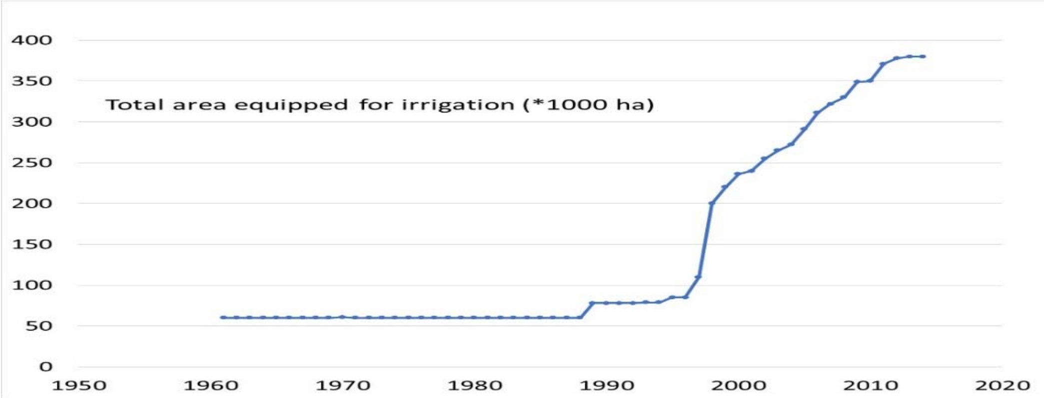


Figure A3: Irrigated area Mali (FAOstat, June 2017)

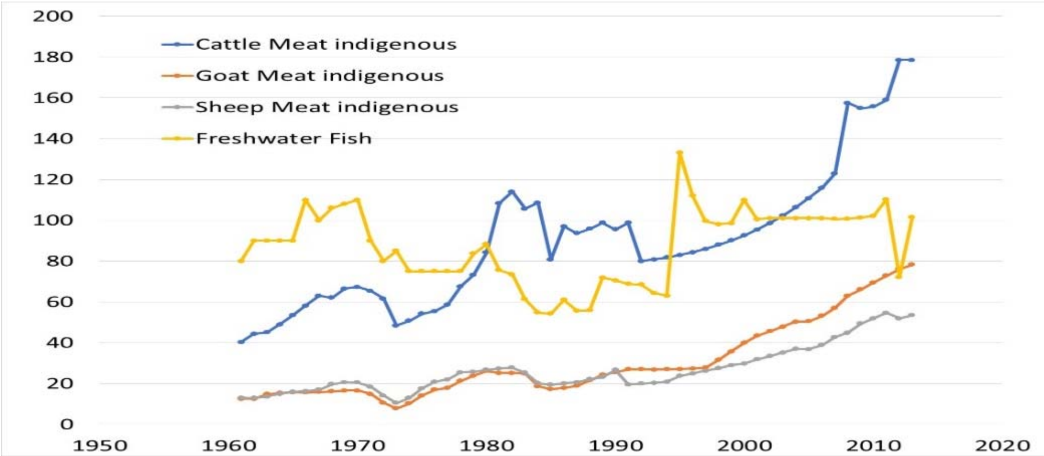


Figure A4a: Meat and freshwater fish production in Mali (*1000 tons)

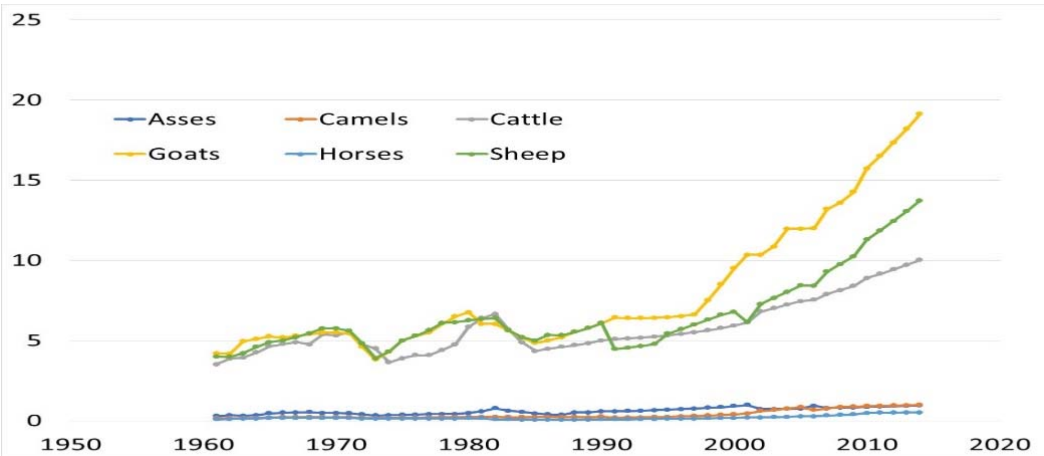


Figure A4b: Number of animals in Mali (Million heads)

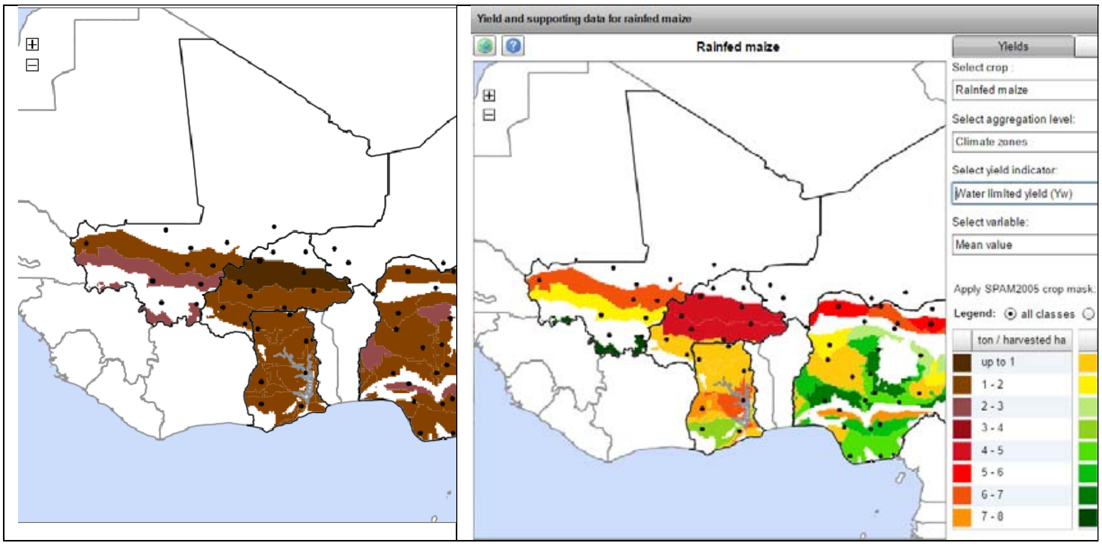


Figure A5a: Actual (Left) and rainfed (water limited) maize yields. Yield Gap Atlas, June 2017

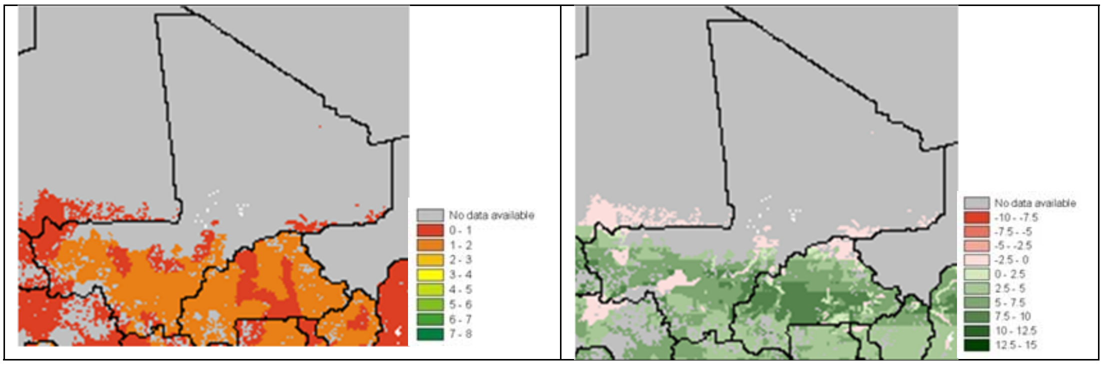


Figure A5b: Actual yield (Left) and calculated grain yields under rainfed conditions (Conijn et al., 2011)

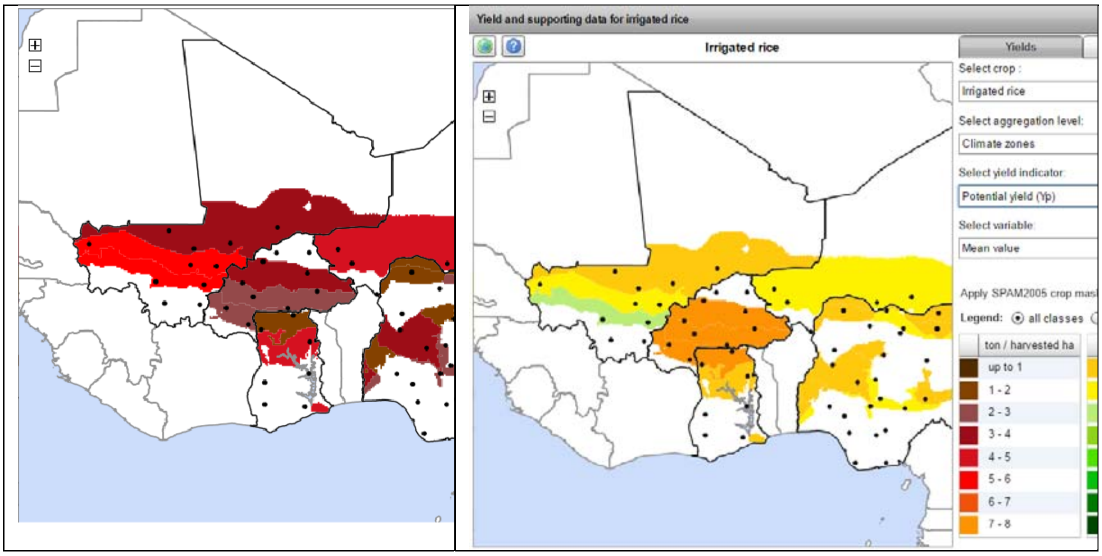


Figure A5c: Actual (Left) and irrigated (potential) rice yields. Yield Gap Atlas, June 2017

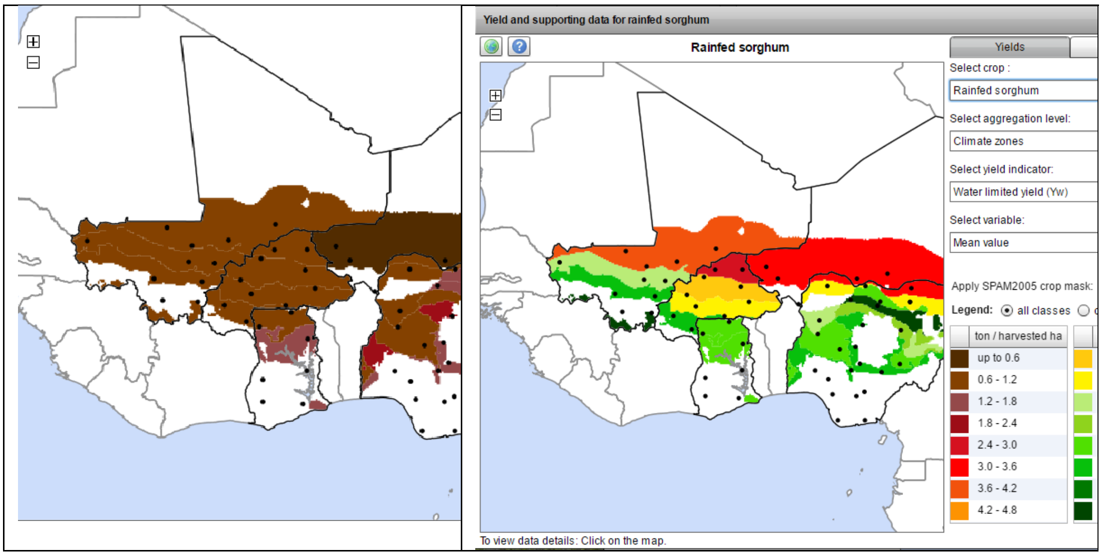


Figure A5d: Actual (Left) and rainfed (water limited) sorghum yields. Yield Gap Atlas, June 2017

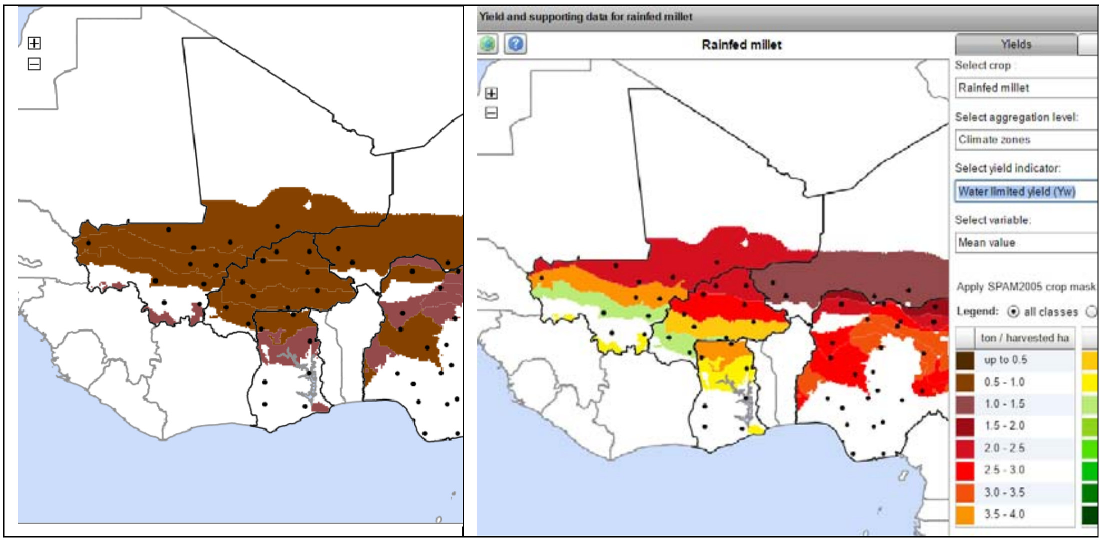


Figure A5e: Actual (Left) and rainfed (water limited) millet yields. Yield Gap Atlas, June 2017

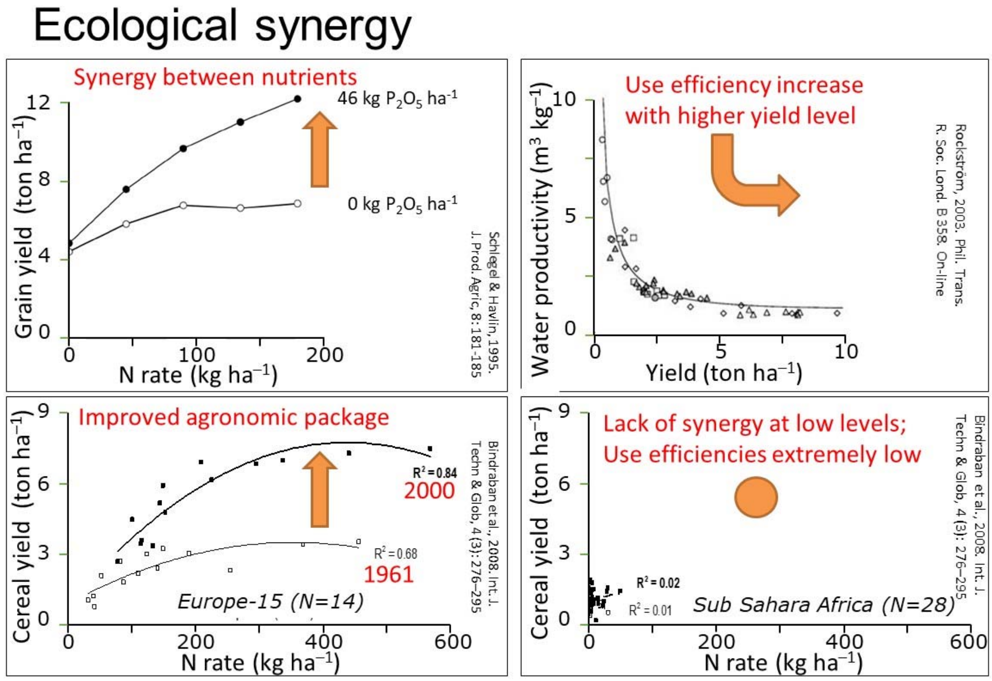
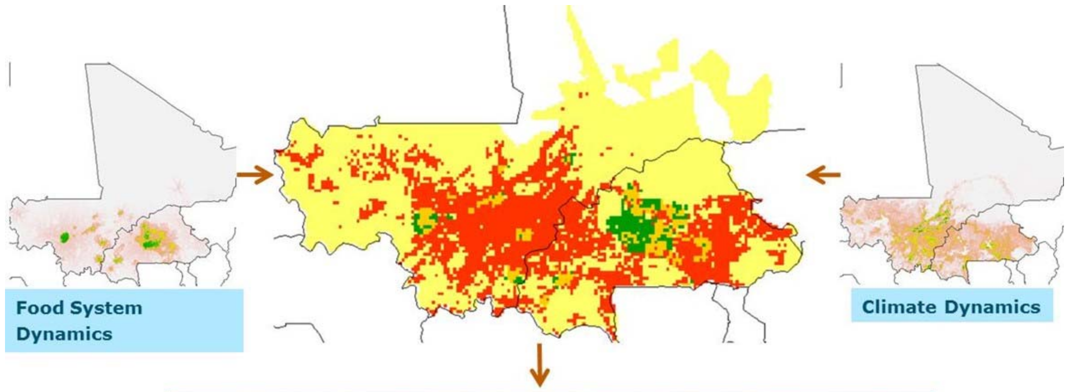


Figure A6: A comprehensive of agronomic measures creates ecological synergy between input factors and raise their overall use efficiency



Index [% of area]	Food System Dynamics Low	Food System Dynamics High
Climate Dynamics Low	Medium [yellow, 62.0%]	High [green, 2.7%]
Climate Dynamics High	Low [red, 31.6%]	Medium [orange, 3.8%]

Figure A7: Areas with high, medium and low potential for climate smart interventions into food systems. A critical political ecology of cotton and soil fertility in Mali